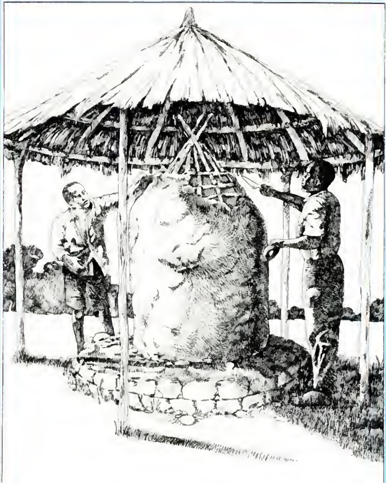
Construction and operation of small solid-wall bins

FAO AGRICULTURAL SERVICES BULLETIN
69



FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

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Prepared by
Ole Bodholt
and
Aliou Diop
Agricultural Engineers

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FOREWORD

The aim of this manual is to provide guidelines for construction and use of small bins with solid walls for storage of threshed grain. It has been attempted to find technical solutions (based mainly on experience from FAO executed projects) which, at present, seem to be realistic and appropriate for adoption by the small scale farmers. It might however be remembered that new constraints will still appear requiring development of solutions. The design and promotion of improved techniques and structures for storage is therefore a dynamic process which needs continuous attention.

1. INTRODUCTION

Small-scale farmers have, for time immemorisl, used a variety of different containers to store their food products. Most of these storage techniques are the results of a long process of empirical trials, modifications and adaptations. In some cases, they have reached a level of equilibrium with the environment and the functional requirements for safe storage.

Very often however, new constrsints have limited the level of efficiency of the traditional storage techniques. They may be listed as follows:

i) Socio-economical constraints:

- necessity to store threshed grain for marketing purposes (for example, grain must be made readily available for sale to get the necessary cash to buy other goods, to pay taxes, etc), whereas storage of unthreshed grain usually is the mastered traditional method.

- migration of work force limiting the availability of manpower for building or maintenance of storage structures.

ii) Ecological constraints

- prolonged drought in some regions might result in the scarcity or even the disappearance of the preferred plant materials used for building of granaries and are well known to farmers for their strength and resistance to termites or even their repelling effect against insect.

- spreading of insects pests (such as *Trogoderma granarium*, *Prostephanus truncatus*) in regions where they were not known before, rendering the storage techniques inefficient for the prevention of food losses.

iii) Technological constraints

- introduction of mechanical threshers in areas where storage is traditionally carried out with unthreshed grain.

- introduction and expansion of cash crop cultivation competing with food crops. For example, the harvesting of the cash crops might coincide with the time when farmers traditionally were collecting building materials for construction of new granaries or doing the maintenance of structures.

- improved production methods resulting in increased yield might require larger storage capacities than the ones of known traditional granaries.

- introduction of new varieties might necessitate the change of storage techniques.

These constraints, some of which occurring simultaneously, have in many cases led farmers to improvise significant changes in storage techniques. Also, government agencies in many developing countries, often assisted by internationally financed projects, have developed and introduced modified techniques and structures in order to solve storage problems at farmers level.

2. STORAGE STRUCTURES AND CONTAINERS USED AT FARMERS' LEVEL

2.1 GOURDS AND POTS

Gourds are small containers which are used traditionally for storage of grain with capacities ranging from 5 to 50 kg. They are made of the dried skin of calabash fruits (figure 2.1). The surface might be treated with oil - Clay pots are made from fine clay which farmers usually will take from special locations, such as proximity of ponds. The freshly shaped clay pot is burnt to increase its strength (figure 2.2).

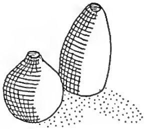


Figure 2.1: Gourds

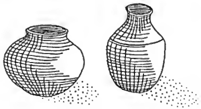


Figure 2.2: Clay pots

These containers are used for the storage of small quantities of produce for immediate consumption or for seed. They are always placed inside a room. When the container is used for the storage of seed or grain legumes, the dry grain is often mixed with ash or sand, filling the container up to the top before it is sealed with mud. The pulverulent material used for mixing i.e., sand, ash or even dry clayey soil, will fill most of the voids left between individual kernels and thus reduce movement of insect pests which will subsequently die.

2.2 GRANARIES

All over the tropics and subtropics, granaries built of mud, as well as of plant and wood materials have been developed by small-scale farmers

and are still in widespread use as the main storage structure for threshed or unthreshed foodgrains. The average capacity, ranging from 500 to 2000 kg of grain corresponds normally to one year consumption for a farmer's family. In areas where large portions of the grain will be marketed later or where unthreshed grain is stored, the granaries may even be larger, i.e. 20 to 30m^3 in volume for all-plant material granaries and up to 400m^3 for mud-built granaries (figures 2.3).

Figure 2.3a: All plant material granary 20-30 m3 capacity.

Figure 2.3b: Mud-built granary for the storage of unthreshed grain

All-plant material granaries

These types of grain stores are naturally open-to-air structures which provide some aeration of the grain. Unfortunately, they are impossible to disinfect totally and subject to infestations from the outside. They are common in the humid tropics where drying of grains down to safe moisture content for storage is difficult.

The structure consists of the frame (figure 2.4) made of wood preferably resistant to termites. The floor and the wall made of mats of woven plant material such as bamboo splits, stalks of grasses like *Andropogon guyanus* or *Imperata cylindrica*, sticks of palm fronds, etc. The structure is normally covered by an overhanging thatched roof (figure 2.5).

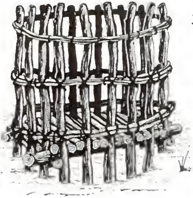


Figure 2.4: Typical frame for an all-plant material granary

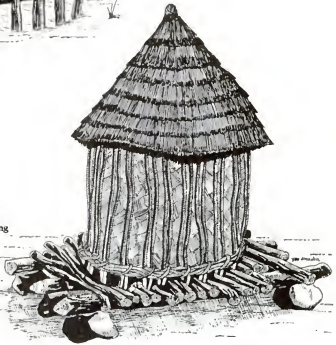


Figure 2.5:

All-plant material granary. Supporting poles have been replaced by large rocks.

When properly built and maintained, this type of granary will last for ten years or more. However, its main disadvantages are:

i) the lack of protection against rodents;

ii) the difficulty to totally disinfest the structure before storage of grain;

iii) the possibility of infestation by insect pests from outside;

iv) the risk of fire.

To the above disadvantages should be added the increasing scarcity of the preferred plant and wood materials because of ecological factors in some regions. This contraint, as well as the increasing necessity to store threshed grain for marketing explain the new trend towards plastering of the wall (figure 2.6) or the adoption of mud-built granaries.

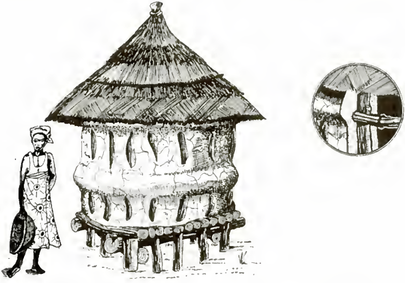


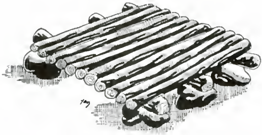
Figure 2.6: All-plant material granary plastered in and out with mud.

Mud-built granaries

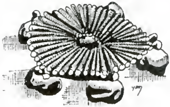
Mud-built granaries are common in drier areas. The reason for this is thst serstion is not so importsnt as the grsin is normally hsrvested with very low moisture content (below 11 per cent).

The granary is normally built on an elevated platform of either wooden materisl or large stones or combination of both. (figure 2.7). The walls are constructed in successive layers using lumps of mud reinforced with straw.

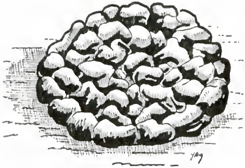
a) Wooden platform on large rocks for square or rectangular floor



b) Wooden platform on large rocks for circular floor



c) Stone base for large size granary



d) Three (or five) rocks for small circular granary

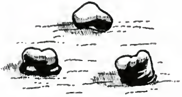


Figure 2.7: Different types of platforms for mud-built granaries

Stores built with successive layers of reinforced lumps will not develop cracks and with good maintenance a lifetime of more than 20 years can be expected. (figure 2.9).

However, the disadvantage of using this technique is that it takes very long time to build a store as layers (10 - 15 cm each) are laid one at a time and must be left to dry at least for one full day. This constraint is the reason for an increasing use of sun dried mud blocks for faster construction.

Figure 2.9: Mud-built granary carefully finished with a fine clay plastering.

2.3 UNDERGROUND PITS

Storage of foodgrains in underground pits has been carried out for centuries in drier areas of the world where the soil water table is sufficiently low. The inside surfaces of the pit are normally lined with straw or any other dry plant material which will absorb any excess moisture from the soil.

The main purpose of using underground pits, in former times, was probably to hide the grain stock from hostile intruders. This, together with the tedious work of building and operating underground pits, might explain their lesser use in our days.

2.4 RECENTLY DEVELOPED STORAGE CONTAINERS AND STRUCTURES

In face of new constraints to traditional storage systems, different types of storage containers and structures have been developed in many countries. However, experience has shown that if such development work shall be successful, then the following important aspects have to be taken into account:

i) availability of building materials;

ii) simplicity of construction and training programme for farmers;

iii) socio-economic aspects of storage at the small farmer level, i.e. cost, prevailing ways and customs of each ethnic group, storage practices i.e. threshed versus unthreshed storage, etc.

Some of the significant improved storage structures are briefly described in Annex I.

3. SOME BASIC PRINCIPLES OF STORAGE IN SOLID WALL BINS

Most farmers in developing countries produce and store grain for their own family consumption, for varied length of time. Very often the small farmers have no additional earnings and the amount of grain stored barely covers the family's needs until the next harvest. Therefore, when considering the building of a new storage structure, they have to look for the cheapest design although that might not be the most desirable and adequate one.

According to these reasons, the general requirements for a solid wall bin structure can be listed as below:

i) the structure must ensure adequate and easy protection of the stored grain against moisture and storage pests;

ii) the structure should be cheap and easy to build and maintain;

iii) it should preferably be made of local material.

The moisture and temperature of the stored grain and the chemical composition of the air within the grain mass are the three environmental factors that most affect the storability of foodgrains. On the other hand, the design and maintenance of the storage structure will determine the level of spoilage due to rodents, birds and termites.

In this chapter, the effects of the environmental factors on insects and moulds development, moisture migration, as well as the importance of appropriate design and maintenance of structures for rodents and birds control will be considered.

3.1 THE CONTROL OF INSECT PESTS POPULATION

Harvested foodgrains, which are dried and stored, are always associated with some insects and microorganisms. The population of these storage pests will increase further as soon as the environmental factors are favourable.

Under normal storage conditions, grain temperature and moisture content are the most important variables that affect insect population growth. Some studies have related the weekly multiplication ratio to the population growth rate of insects as in the following formula:

$$N = N_o M^t \qquad \text{(equation 3.1)}$$

Where: N = number of insects after a time t;

No = initial number of insects;

M = weekly multiplication ratio;

t = time, weeks.

From figure 3.1 it is clear that the weekly multiplication ratio, M, is strongly related to grain moisture content and temperature. A reduction in either grain moisture content or temperature will result in a lowered rate of insect population growth.

Equation 3.1 has been given just as an example to illustrate how fast the insect population may grow when environmental factors are not properly controlled.

For safe storage of foodgrains in solid wall bins, the grain moisture content must be kept evenly distributed and as low as possible. The recommended moisture contents shown in table 3.1 are those in equilibrium with air at 70% relative humidity at 27°C.

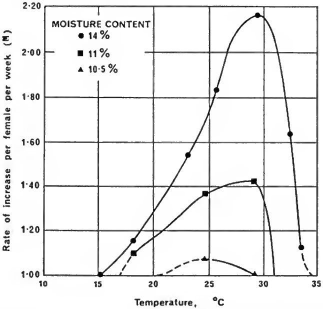


Figure 3.1: The variation of weekly multiplication ratio of Sitophilus oryzae (small strain) with temperature and moisture content of wheat (after Birch, 1953).

Table 3.1: Recommended maximum moisture content for safe storage of cereals and pulses (adapted from Muckle and Stirling, 1971)

TYPE OF GRAIN	MOISTURE CONTENT (%)
Shelled maize	13.0-13.5
Rough rice	13.0-14.0
Sorghum	13.0-13.5
Millet	15.0-16.0
Wheat	13.5
Beans	14.0-15.0
Soybeans	10.0-11.0

Modification of the chemical composition of the intergranular air by the use of airtight storage is quite an effective non chemical method for the control of insects. The basic principle of airtight or nearly airtight storage is the natural depletion of the level of oxygen available to dependant organisms, be they insects or moulds, before they can cause any serious damage to the grain. The reduction of oxygen content within the airtight structure is usually due to the respiration of the stored produce and its associated pests.

Although the rate of respiration is low in dry, uninfested grain, it increases rapidly if the grain is infested by insects and moulds, the increase being greater at a higher temperature (see figure 3.2).

When dry grain infested by insects is stored in an airtight container, the insects will soon use up the available oxygen. The more the grain is infested and/or the available air volume is low, the faster will be the oxygen depletion.

For example, if the population of insects is about 13 adult grain weevils per kg of grain, the oxygen will be reduced to a lethal level in 21 days. With a higher population density of 133 adult grain weevils/kg of grain and with the same quantity of air available, the concentration of oxygen is reduced to less than 2% in only 4 days. Most insect species in a stored product are killed when the oxygen concentration of the intergranular air falls below 2% by volume (see figure 3.3).

The viability of grain stored in airtight containers has been reported to be reduced. Such reduction is greater, the higher the moisture content is. Grain from such containers might not be suitable as seed.

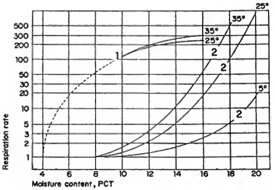


Figure 3.2: Respiration rate of wheat and weevils under different conditions. (1) Respiration of weevils mg CO_2/day x gram of weevils, (2) Respiration of wheat, mg CO_2/day x kg. Data extracted from Pixton & Warburton (1971) and Bailey & Gurjar (1918).

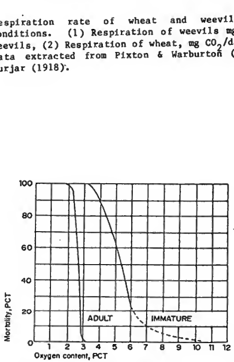


Figure 3.3: Mortality of adult and immature atages of Sitophilus granarius in atmospheres of oxygen. (Compiled from Bailey, 1955).

However, for small scale storage, containers made of metal or plastic are the only ones which can provide for the needed level of airtightness for pest control without use of chemicals. Taking into account that the structures should also be cheap and easy to build, small solid wall bins are difficult to be rendered airtight while only available local material, i.e. mud, straw, wood or even cement are to be used.

The population of insects may also be increased by infestation from outside or by residual infestation, i.e. by insects already inside the store before the new stock arrived. Traditional granaries which are often just protected at the top of walls by a straw roof cannot prevent insects from coming in. Furthermore, the straw roof and cracks on inside surfaces constitute ideal places for insects to hide and breed.

Proper protection against these sources of reinfestation can only be achieved through adequate design of insect proof structures that have to be properly maintained and managed. As airtightness for pest control purposes without use of chemicals is difficult to achieve in these small scale types of structure, development of designs should be directed towards sealed structures which will be moisture proof and pest proof. Appropriate protection against temperature variations within the bin should also always be provided.

Treatment with recommended insecticides is necessary for safe storage of grain in a sealed but not airtight bin, specially when the duration of storage might exceed 6 months for cereal grains. However, some advice from the competent national service or institution, for example the Plant Protection Service, may be needed before the use of a new insecticide on stored foodgrain.

3.2 PROTECTION AGAINST MOULDS

Moisture is the most determinant factor that influences mould development. Drying of foodgrains to safe moisture content levels defined in table 3.1, and keeping them cool and dry is the only effective and appropriate method to prevent the stored product from getting mouldy in small scale stores. Properly designed and maintained stores facilitate the protection of dry grain from mould damage.

3.3 MOISTURE MIGRATION

Even dry grain in good condition that is stored for a prolonged period of time may still be prone to serious spoilage arising from redistribution of moisture in the mass of grain. The main cause of moisture migration is temperature gradients within the bulk which gives rise to convection currents. As warm air passes into a region of cool grain its relative humidity increases. This produces an increase in grain moisture content and sometimes "caking" in the cooler areas of the grain mass. For example, a storage bin which is directly exposed to solar radiation will show temperature differentials between the inner portion of the grain mass and the surface of the grain, during cool nights. This will give rise to moisture migration from the hot parts of the grain mass to the cooler ones.

The higher the temperature differentials, the more serious problems are likely to occur due to moisture movement. The most effective method for the control of temperature differentials arising from radiation consists in the shading of the storage structure.

In humid tropics, where grain is likely to be harvested and stored damp, heat of respiration is likely to give rise to serious problem of moisture migration also. Damp grain should normally be dried before it is stored.

Insect infestations in both dry and moist grain also exaggerate the problems of moisture migration. The infestation may start in a small region of grain, and the metabolism of the insects raises the temperature to about 40°C. This is called a "hot spots". As temperatures above 40°C are lethal to most grain storage insects, the infestation spreads to cooler and more hospitable regions until it occupies the entire grain bulk. The temperature differentials between "hot spots" and the rest of the grain mass will create moisture migration. A good method to prevent this process from starting and building up is to properly apply insecticide treatment to the infested grain before putting it into storage.

3.4 PROTECTION AGAINST RODENTS AND BIRDS

In order to be effective, the control of rodents and birds at village level must be a preventive one: any access to the stored grain by these pests should not be allowed. The preventive control measures should start as soon as the design phase of the structure, with:

i) the selection of adequate rat proof building materials, for the accessible part of the structure;
ii) the use of appropriate construction devices as barriers against rodents and birds, i.e. rat guard, fine wire mesh, etc.;
iii) tightly fitting the junction of the wall to the roof structure.

While operating the storage structure, cleanlineas around the bin is also of great importance in order to keep rodents and birds away. All the scrub and any object which may hide rodents should be removed from an area about 3 to 5 meters around the bin. This area must remain clean and always free of burrows or spilled grain which may attract rodents and birds.

4. DESIGN PARAMETERS AND DESIGN OF SOLID WALL BIN COMPONENTS

To correspond to farmers real needs, any improved design should be aimed at solving one or more identified constraints on the already existing storage system. The new structure should not differ too much from the existing traditional stores or require drastic changes.

For example, the farmers from a given region may have difficulties to find the adequate plant material normally used for the construction of the traditional thatched roofs of their granaries. This leads to use of a weaker material, which does not last long and is not water proof. In this case, a solution to the identified problem may only consist in the design of an appropriate roof structure which, together with the other existing components of the bin structure, will satisfy the general requirements of being cheap and easy to build by farmers themselves, as well as ensuring adequate protection of the stored grain against storage pests, moisture and excessive temperature fluctuations. Therefore, the extension personnel should be in a position to be able to propose appropriate solutions for particular areas and also for individuals specific problems, still taking into account the general requirements for small stores.

The following chapters give some guidelines on the design of each of the bin components, for instance, the foundations, the floor, the wall and roof etc. The proposed designs should not be considered as ultimate solutions. They may need to be modified or adapted according to specific conditions.

4.1 FOUNDATION AND FLOOR

4.1.1 Functional Requirements

For safe storage of grains and pulses, foundations and floors should:

i) Protect the bin from flooding;

ii) Provide security against capillary and diffusing moisture;

iii) Be insect proof;

iv) Be rodent proof;

v) Have a surface which is easy to clean and without cracks where insects can breed;

vi) Be strong enough to resist the vertical pressure from the stored produce.

4.1.2 Floors Directly on the Ground

It should be noticed that this type of structure needs to be rat proof from ground level up to approximately 20-30 cm. This can be achieved by using some harder materials in this section of the bin.

The load bearing capacity of most soils will usually be big enough to match the verticsl pressure from the bin (see table 4.4). Two meters high of shelled maize stored in a bin will for instance produce a vertical load of approximately 10.7 kN/m^2 on the floor and foundation, part of the grain load being transferred to the wall (see equation 4.3 and table 4.5). To this load should be added the dead load of the bin (see tables 4.3 and 4.9). For small shallow bins, the total vertical load on the floor can normally be supported safely by even soft clay soil. Figures 4.1 (a through d) show cross sections of different floor structures built directly on the ground. Details from one floor structure may be incorporated in some of the other structures. For instance, the damp proof layer from figures 4.1a and 4.1b may be applied in figure 4.1d as well.

The risk of moisture uptake through the floor can be reduced by draining away the rainwater. This is simply done firstly by choosing sites where rainwater does not accummulate and secondly by digging small storm drains around the floor area.

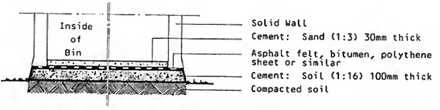


Figure 4.1.a: Concrete floor on a damp proof layer

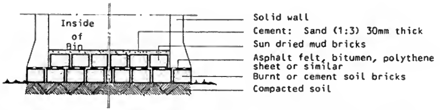


Figure 4.1.b: Concrete floor on a layer of bricks and a damp proof layer

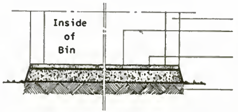


Figure 4.1.c: Concrete floor made of moisture proof concrete mix

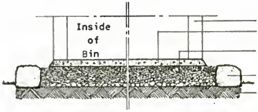


Figure 4.1.d: Concrete Floor on a capillary breaking layer

4.1.3 Floors on an Elevated Stone Base

This design is particularly well suited for areas where heavy rainfalls occur. The large and clean stones used in the base are stacked to a height of 30cm. They are not grouted so as to prevent capillary transmission of moisture from the ground to the floor. The floor could be either a reinforced concrete slab, a mud and cowdung floor or a metal sheet.

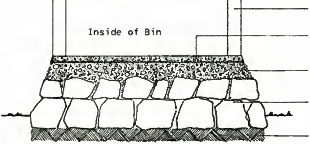


Figure 4.2: Cross section of elevated stone base.

4.1.4 Floors on an Elevated Platform

The platform may be constructed of either mud - cowdung mixture on wooden poles or a concrete slab as mentioned for the elevated stone base. If wooden poles are used, they must be treated against termites with bitumen, used engine oil or any other suitable product. The load on the individual posts or pillars might be considerable and exceed the soil bearing capacity. It is necessary to calculate the total load on the individual poles and arrange for adequate footing area, see chapter 6.

Concrete or brick-built pillars might be of interest, specially in places where adequate wooden poles are not available.

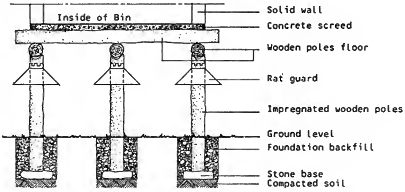


Figure 4.3: Floor on an elevated platform built on wooden poles

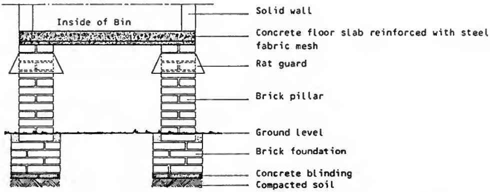


Figure 4.4: Floor on an elevated platform built on brick or concrete pillars

Table 4.1: Functional requirements and their relation to different constructions of floors and foundations (see figures 4.1 and 4.4).

STRUCTURE	Protecting from flooding	Moisture proof	Insect proof	Rat proof	"Airtight"	Easy to clean
Floors on the ground:						
Concrete on damp proof layer	o	+	+ o	+ o	+	+
Bricks under and over a damp proof layer	o	+	+ o	+ o	+	+
Damp proof concrete	o	+ o	+	+ o	+	+
Foundations:						
Stone base	+	+ o	+	+ o	-	
Poles	+	+	+	+	-	-
Pillars	+	+	+	+	-	-
Floors on foundations:						
Wooden beams + mud or concrete	+	+ o	+ o	+ o	+ o	+
Concrete slab	+	+ o	+	+ o	+	+
Wooden sheet/board	+	+ o	o +	+ o	+	+
Metal sheet	+	+	+	+	+	+

\+ the functional requirements are fulfilled by the construction.

o the construction does not fulfill the requirements.

o + means that special measures have to be taken to achieve the (+) conditions.

\- do not apply.

Table 4.2: Approximate list of quantities for different constructions of floors and foundations for small solid wall bins (500-3000 kg), see figures 4.1 - 4.4.

STRUCTURES	APPROXIMATE LIST OF MATERIALS PER M^2						
	Cement	Sand or soil	Gravel stones or bricks	Poles or pillars	Beams or sheets	Iron bars	Asphalt or PVC
Floors on ground:							
Figure 4.1.a Concrete on a damp proof layer	$0.02m^3$	$0.13m^3$	$0.05m^3$	-	-	-	$1m^2$
Figure 4.1.b Bricks under and over a damp proof layer	$0.01m^3$	$0.04m^3$	100 bricks*	-	-	-	$1m^2$
Figure 4.1.c Damp proof concrete	$0.02m^3$	$0.04m^3$	$0.05m^3$	-	-	-	-
Figure 4.1.d Concrete on a capillary breaking layer	$0.01m^3$	$0.02m^3$	$0.05m^3$	-	-	-	-
Foundations:							
Figure 4.2 Stone base	-	-	$0.5m^3$	-	-	-	-
Figure 4.3 Poles	-	-	Stones for footing	6m Ø>10 cm	3m Ø10 cm	-	-
Figure 4.4 Pillars (Concrete	$0.1m^3$	$0.3m^3$	$0.5m^3$	-	-	-	-
Figure 4.4 Pillars (Bricks	$0.002m^3$	$0.012m^3$	-	56 bricks	-	-	-

Floors on foundation: can be placed on any of the foundations shown in figures 4.2 - 4.4.

	Cement	Sand or soil	Gravel stones or bricks	Poles or pillars	Beams or sheets	Iron bars	Asphalt or PVC
Wooden beams (mud		$0.1m^3$					
Wooden beams (concrete	$0.02m^3$	$0.05m^3$	$0.1m^3$	-	15m Ø8	-	$1m^2$
Concrete slab**	$0.02m^3$	$0.05m^3$	$0.1m^3$	-	-	10m Ø 7mm	-

* 50 burnt bricks + 50 mud bricks.
** Only reinforced when the slab is resting on pillars or poles.

Table 4.3: Typical allowable bearing capacities.
(From "Farm Structures in Tropical Climates",FAO, 1986 - Edited by Bengtsson and Whitaker)

Material	Allowable bearing capacity (KN/m^2)
Plain concrete	2000 - 6000
Masonry	1500 - 5000
Compact sands and gravels	300 - 600
Loose sands and gravels	150 - 400
Hard clays and soft rocks	300 - 600
Stiff clays and sandy clays	150 - 300
Firm clays and sandy clays	75 - 150
Soft clays and silts	0 - 75
Fill and made ground	Variable

Note: The above values for soils apply where the foundation is 1 m or more wide and at a depth of at least 0.6 m.

4.2 WALL STRUCTURE

The walls and the top of the bin are usually made of the same materials. In principle, the wall structure should fulfill some functional requirements. The wall should be:

i) sufficiently tight to prevent entrance of insects;

ii) strong enough to resist the horizontal pressure from the stored grain;

iii) bird proof;

iv) rodent proof if not otherwise protected (see 4.1 floor structure and foundations);

v) easy to clean and without inside cracks;

vi) resistant to wind forces.

The wall types which will be discussed in this chapter should always be provided with additional protection against rain and direct solar radiation (see chapter 4.4).

4.2.1 Airtightness of the Wall

The importance of airtightness of the structure is discussed in chapter 3. The conclusion is that only some metal or plastic containers can provide completely airtight conditions, but medium term storage of dry grain and pulses is possible even if the bin is not completely airtight.

4.2.2 Pressure Loads on Wall

Apart from its own weight (dead load) and other loads it may carry, for instance the roof, the wall of a cylindrical bin loaded with grain is exposed to two main stresses:

i) horizontal (or lateral) pressure P_h, due to the grain load; this causes a circumferential tension inside the wall structure;

ii) vertical friction pressure, Pv, due to friction of grains against the walls; this generates vertical compression stresses on the wall.

For small bins, however, it can be calculated that when the wall thickness is dimensioned to withstand the tension stress, the wall will also be strong enough to resist the vertical compression stress due to grain friction. There is therefore no need to check the wall strength against vertical compression stress.

The wall should only be calculated to withstand the tension stress.

The wall thickness, t, should at least be equal to:

$$t = \frac{R.P_h}{T_s} \qquad (4.1)$$

where: t = wall thickness, (m)

R = inside radius of the bin (m)

P_h = maximum horizontal pressure (kN/m^2); see table 4.5

Ts = maximum tensile strength of wall material (kN/m^2); see table 4.6

Values of P_h in table 4.5 are obtained by using the following Rankine's formula which is quite adequate for small bins:

$$P_h = \frac{w.h.\ (1-\sin\emptyset)}{102.\ (1+\sin\emptyset)} \qquad (4.2)$$

where: P_h = lateral pressure on wall (kN/m^2)

w = specific weight of the grain (kg/m^3)

h = depth of the stored grain (m)

$\emptyset$ = internal friction angle of the stored grain (degree)

The grain load on the floor can be calculated using the following formula:

$$V = \frac{P_h}{K} \tag{4.3}$$

where: V = total vertical load of grain on the floor, (kN/m^2)

P_h = lateral pressure on wall, as in equation 4.2, (kN/m^2)

K = ratio of lateral to vertical pressure of grain, generally between 0.3 and 0.6 (see table 4.4).

Table 4.4: Specific Weight and Internal Friction Angle of Grains

Grain	Specific weight (kg/m^3)	Internal friction angle (Ø) (degrees)	Sin Ø	Lateral to vertical pressure ratio, K
Maize	719	22	0.375	0.6
Rough rice	578	30	0.500	0.5
Sorghum	719	27	0.454	0.3
Millet	700	25	0.423	0.3
Soybeans	719	22	0.375	0.4

Table 4.5: Approximate Lateral Pressure (Ph) on Wall of Small Cylindrical Bins

Height of stored grain (m)	Lateral pressure *(kN/m^2) when bin loaded with:			
	Paddy	Sorghum	Millet	Maize
1.0	1.5	2.6	2.8	3.2
1.5	2.2	4.0	4.2	4.8
2.0	2.9	5.3	5.6	6.4
2.5	3.7	6.6	7.0	8.0
3.0	4.4	7.9	8.4	9.6

* Lateral pressures are calculated using Rankine's formula.

Table 4.6: Approximate maximum allowable tensile strength of different building materials

Material	Tensile strength (kN/m^2)
Clay soil, dry	30 - 60
Burnt clay products:	
Half burnt	400 - 1500
Full burnt	2200
Hard burnt	3000
Very hard burnt	4000-4500
Cement mortar:	
1:4 cement: sand	4500
1:8 " "	2500
1:15 " "	1000
Wood:	
Parallel to fibres	8000-12000
Perpendicular to fibres	200-300
Common steel	450000

4.2.3 Insect Proofness

Insect proofness is one of the major advantages of the solid wall bin. It is however, difficult to obtain unless the structure is carefully built and maintained. Even small cracks in the wall will allow penetration of insects. Therefore any attempt to avoid cracking should be made.

For structures utilizing cement based building materials, development of cracks can be avoided using the dryest possible mixture of sand-cement and water for the construction. A concrete with a water: cement ratio of about 0.5 is quite adequate.

For the mixing, the recommended procedure is as follows:

i) Pour the required amount of water into a bowl;

ii) Add the double amount of cement while stirring the mixture carefully;

iii) Add the cement slurry stepwise to the sand or soil and mix very carefully. The mixing should preferably be done in the shade;

iv) cover the mix with plastic, green banana or palm leafs, grass or wet paper or jute bags. Let it stay for some 10 minutes;

v) Remove the covering material and remix the concrete with a shovel.

The mixture should be used within 20-30 minutes.

As regards wall materials based on soil, adding of chopped grass (2-3cm), straw or sisal fibres into the mixture will help to avoid cracking and increase the tensile strength of the structure. Adding bitumen and wax to the mortar for plastering will also reduce the shrinkage and swelling of mud and soil cement walls.

However, the most effective measure to reduce cracking in both types of walls is to protect them from drying out too quickly. This can be done by covering the freshly built walls with used jute bags and sprinkling them with water every 3-4 hours every day for at least one week.

4.2.4 Rodent Proofness

Rodent Proofness of the bin can only be obtained either by using rodent proof foundations or, if this is not the case, walls made of metal, concrete, bricks or cement-plastered mud construction. Secondary measures are of course cleanliness around the bin to reduce the number of rodents and birds being attracted by the bin and its surroundings.

4.2.5 Ease of Cleaning

The inside surface of the walls should be smooth and easy to sweep or even to wash. For that purpose, no cracks where insects can hide should be allowed and wall to floor junction should be rounded in order to make the cleaning easier.

4.2.6 Resistance to Climatic Factors

For all solid wall bin structures in tropical regions, it is always recommended to avoid direct exposure to climatic influences, both because of the disintegration caused by rain and sunshine and in particular because of the risk of moisture migration in the stored grain causing condensation.

The construction of the bin under a shed structure or just covering its upper part with an over hanging thatched roof will help avoid all these problems (see Chapter 4.4).

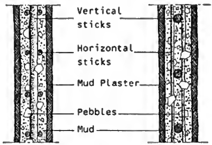
All structures except those made of metal sheets will be able to resist the wind forces even if they are empty.

Figure 4.5: Cross section of different wall structures.

VERTICAL SECTION HORIZONTAL SECTION

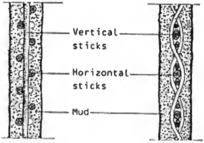
a. Traditional mud and sticks wall

The mud-cowdung plaster may be reinforced by mixing in chopped grass, sisal fibres etc.
Spacing of vertical sticks varies from 5-25 cm and for horizontal sticks 5-15 cm.
Thickness of wall is usually 15-25 cm



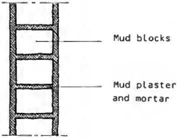
b. Mud or cement-plastered basket wall

The mud plaster might be nearly water proof when mixing in 2 kg bitumen and 0.25 kg wax per 0.03 m^3 of soil.
If soil cememt is used, the clay content of the mud or mortar should be 25-40%.
Annex 2 gives a simple soil test for the determination of clay content.
Mixture should be 1:4 (cement: soil).
Horizontal sticks, Ø = 1-2 cm,
Vertical sticks, Ø 2-3 cm.
Thickness of wall is usually 6-8 cm.



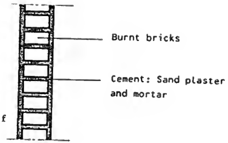
c. Mud wall

When rain is not a problem, rammed soil or mud blocks are appropriate materials. It is recommended to mix in chopped grass or other fibreous materials as in a) above and bitumen/wax as in b. Plastering with mud-cowdung will also do well.
Thickness of wall is usually 12-14 cm.



d. Walls made of well burnt bricks

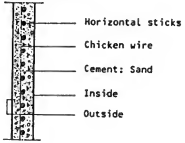
This wall structure is often used in combination with floors directly on the ground. The use of burnt bricks can be limited to the lower 40-50 cm of the wall to make it rodent proof while the rest can be plastered soil-cement blocks. Thickness of the wall is usually 12-15 cm.



e. Ferro-cement wall

During construction of the ferrocement wall the built-in chicken wire is supported by a frame structure of horizontal and vertical sticks. When one side is plastered, part of the frame can be removed before plastering the other side. Usually the laths are left in the structure, because they are difficult to remove without spoiling the first layer of mortar. Thickness of the wall is usually 5-7.5 cm, but with a high level of craftmanship, even thinner walls can be built.

VERTICAL SECTION



f. Metal wall

The metal wall is usually made of galvanized or plain iron sheet approximately 0.5 mm thick. (gage 26 or 29) The poor thermal quality of metal makes it absolutely necessary to place this bin type under the shade.

Table 4.7: Functional requirements and their relation to different wall structures. See figure 4.5 a-f.

STRUCTURE	"Airtight" if required	Resist pressure of stored products	Insect proof	Bird proof	Rodent proof	Easy to clean	Resistant to rain	Resistant to drying (no shrinkage)
a. Traditional mud and sticks walls	o	+	+ o	+ o	o	o	o	+
b. Mud or cement plastered "basket" walls	o	+	+ o	+	+ o	o +	o	+
c. Mud walls made of in-situ mud or sun dried mud blocks	o	+ o	+ o	+	+ o	+ o	o +	+
d. Wall made of burnt briks or soil-cement blocks or sand-cement blocks	+ o	+	+	+	+	+ o	+ o	+
e. Ferro cement walls	+ o	+	+	+	+	+ o	+	+ -
f. Metal walls	+	+	+	+	+	+ -	+	-

+ o in the table means that special measures have to be taken to achieve the (+) condition.
- does not apply.

Table 4.8: Approximate list of quantities for different wall structures (see figures 4.5 a-f)

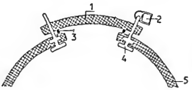
WALL STRUCTURES	APPROXIMATE LIST OF MATERIALS PER m^2 OF WALL							
	Cement	Sand or soil	Gravel or stone	Blocks or bricks	Poles or sticks	Chicken wire 12mm	Polythene Asphalt felt etc.	Sheets of metal or wood
a. Traditional mud and sticks structure	-	$0.1m^3$	$0.02m^3$	-	3m, Ø 6m 20m, Ø 3m	-	-	-
b. Mud or cement plastered "basket wall"	-	$0.08m^3$	-	-	50-100m Ø 1-2cm	-	4 kg bitumen 0.5 kg wax	-
c. Mud walls) in situ) sun dried) mud blocks) 10x25x30cm	- cement mortar 1:16 $0.003m^3$	$0.3m^3$		30 blocks			) 2 kg bitumen) 0.3 kg wax	-
d. Brick walls) burnt br.) soil-cem.) sand-cem.)) 14x14x29cm	$0.01m^3$ $0.02m^3$	$0.05m^3$ $0.16m^3$	-	55 bricks 22 blocks	-	) eventually) $1m^2$	) 2 kg bitumen) 0.3 kg wax	-
e. Ferro cement walls thickness = 3.5 cm	$0.02m^3$	$40dm^3$	-	-	Temporary framework	$2.2m^2$	-	-
f. Metal walls	-	-	-	-	-	-	-	$1m^2$ of iron-sheet

4.3 INLET AND OUTLET

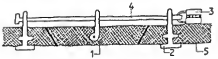
INLET

The inlet is usually located at the top of the bin or the upper part of the walls. The latter makes it impossible to utilize the entire volume of the bin to store the grain. The inlet should have a dimension allowing a small person (boy or girl) to enter the interior of the bin for unloading the portion of grain that cannot run out by itself, as well as for cleaning the floor and walls before next season's crop is loaded.

It is recommendable to look for inlet and outlet constructions that can be secured by a padlock or other lock systems to prevent pilferage.

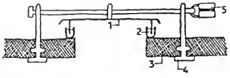


1. Lid
2. Padlock
3. Sealing
4. Eyebolt
5. Roof



1. Lid
2. Eyebolt
3. Padlock
4. Security bolt
5. Roof

Figure 4.6: Examples of inlet made of precast concrete



1. Lid
2. Insect proof sealing
3. Roof
4. Eyebolt
5. Padlock

Figure 4.7: Example of inlet made of metal

OUTLET

The width of the outlet should not be less than 12 cm, thus giving enough room for the removal of the grain by hand.

In order to control the outflow, it is recommended to build the outlet with slopes not exceeding 5-10 degrees. Even nearly horizontal spout will perform well, as the grain is easily removed by hand.

A sufficient length should be at least 20-30 cm outside the wall. This will allow a small container to be placed below the outlet when some grain has to be drawn from the bin. However, the free part of the outlet is very vulnerable to physical damage and should be protected by pillars, poles etc.

The outlet should preferably be made of iron or plastic pipe with tight-fitting lid. A good substitute is a pipe made of ferro cement, figure 4.8.

To build the outlet from ferrocement pipe, form a cylindric pipe of chickenwire in the required length. The diameter should be 15 cm or more. Use a pole as frame. Plaster it outside with a 1.5 cm thick layer of mortar 1:4, cement:sand. Let is cure for 2 days or more. Keep it well damp and handle with care. Plaster it inside by hand or push a stick through for smoothing the surface. Let it cure under damp conditions for a week before it is fixed to the bin.

Usually the grain is removed regularly from the bin over a long period of time, e.g. 6-12 months. Each time the outlet is opened it is a recommendable practice to take out the amount of grain needed for 2-4 weeks or more and store this small amount in a "gourd" or clay pot close to the kitchen.

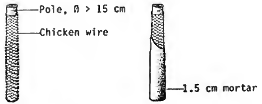


Figure 4.8: Outlet spout made of ferro cement.

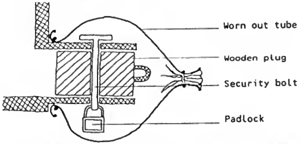


Figure 4.9: An outlet construction that can be secured by a padlock.

4.4 ADDITIONAL CLIMATIC SHELTER

Besides the built-in climatic protection of the different bin structures it is recommended to introduce some additional shelter. The traditional thatched roof secured on top of the bin is the cheapest and most common method of protecting the structure sgsinst rsin and solsr radiation. A rectangular or circular shed structure may also be used provided that the sdditional cost of construction is kept ss low ss possible (figure 4.10).

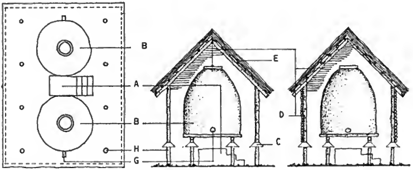


Figure 4.10: Plan and section of rectangular shed protecting 2 solid wsll bins from severe climatic influence.

A = Loading platform and ladder. The ladder should always be removed when not in use.
B = Two solid wall bins.
C = Rat guards
D = Horizontal sticks to protect the bin from direct sunshine snd from wind driven rain.
E = Steep roof with big overhang to protect the bin from sunshine and wind driven rain.
F = Free room between inlet opening and roof should not be less than 75 cm.
G = Outlet opening
H = Poles

Where wind-driven rain is frequent it might be necessary to use s hip-roof structure or protect the gable end by horizontal sticks as in D.

5. EXAMPLES OF IMPROVED TRADITIONAL BIN STRUCTURES

This chapter will give a description of how to build an improved basket type bin with two possible types of foundation. Some other improved solid wall bin types are also described in Annex I.

5.1 ELEVATED PLATFORM ON POLES FOR A 130 CM DIAMETER BIN HOLDING APPROXIMATELY 10 BAGS OF GRAIN

List of material:

- 4 Poles, length 170 cm, diameter 15 cm. Treated with tar oil or used engine oil
- 4 pieces of plain metal for rodent baffles, see figure 5.2
- 2 beams, length 180 cm, diameter 15 cm
- 20 sticks, length 150 cm, diameter 6-7 cm
- 20 sticks, length 150 cm, diameter 1-3 cm

The poles, beama and sticks should be straight hardwood and free of bark. Building procedure:

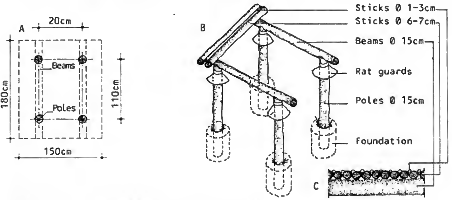


Figure 5.1: The elevated platform on poles.

A = Sketch showing the position of the poles
B = Sketch showing poles, beama and sticks.
C = Detail of wooden platform, cross section, showing small sticks placed between the bigger sticks.

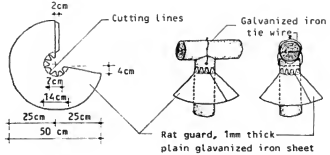


Figure 5.2: Piece of plain metal for conical rodent baffles.

Dig holes, Ø = 30 cm, depth = 65 cm as in figure 5.1 A. Place a stone or a concrete footing in the bottom of the holes. Place the poles and refill the bottom of the holes. Place the poles and refill the soil in layers of 20 cm. Compact each layer well and mix eventually some anti-termite poison. Advice should be sought from the Plant Protection Service for the proper insecticide to use.

Place 2 beams on the poles and tie them using wire, fibre, bark, etc. Place some 20 sticks on the beams thus creating the platform. Tie the sticks to the beams (see figure 5.1 B). Place approximately 20 small sticks in the space between the big sticks to give a levelled and tight surface to the platform.

Fit and fix the conical rodent baffles to the poles as close to the platform as possible (figure 5.2).
The basket can now be placed on the platform for final plastering.

5.2 ELEVATED PLATFORM ON A STONE BASE AS FOUNDATION FOR A 130 CM DIAMETER BIN HOLDING 10-15 BAGS OF GRAIN

Approximate list of materials:
1.4 m^3 big clean stones
0.1 m^3 crushed stones or pebbles
0.15 m^3 of sand
0.05 m^3 of cement

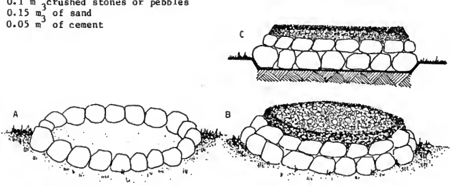


Figure 5.3: Building a stone base for a solid wall bin.

A = Circle of big stones
B = Stone foundation levelled with pebbles
C = Cross section of the foundation

Select a dry site close to the living house. Clear the site from grass and bushes. Mark out the circumference of the foundation. The radius of the foundation at the bottom should be equal to the radius of the basket + 40 cm.

Remove the topsoil to a depth of 5-10 cm inside the marked-out foundation. Place the biggest stonea along the circumference and fill out the interior of the circle as well. Build one or more layers of big stones on this base until the height of the foundation is 40-45 cm. Each stone should be carefully placed and eventually supported by pebbles to make a firm foundation.

Fill in the gaps between the big atones in the top layer with crushed stones or pebbles.

Check that the surface is in level.

Add a 5 cm thick 1:4, cement: sand mortar on the pebbles. For rodent proof stone baae foundation, see figure 4.2.

The basket can now be placed on the foundation for final plastering.

Building a basket type bin, Ø 130, height 85 cm to bending

List of materials:
- 34-51 sticks or split bamboo, Ø 1-2 cm, length 180 cm 280 m of recently cut sticks of lantana, mulberry etc., eventually split bamboo, diameter 1-1.5 cm;
- Fibres, wires etc. for tying;
- Clay soil, cowdung, cement, chopped grass, bitumen, wax etc. A mixture of any available material known to produce a good mortar for plastering, e.g. a sand:cement mortar, 4:1:
- 40 cm pipe of plastic, iron, reinforced concrete etc. for the outlet, diameter 12 cm.

Procedure: see also figure 5.4.

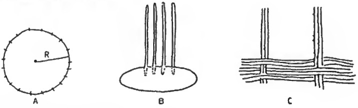


Figure 5.4 Building a basket type bin
A = Circumference of the basket
B = Vertical sticka standing in 15 cm holes in the ground
C = Weaving the horizontal aticks.

Mark a circle on the ground equivalent to the diameter of the basket. Leave a peg in the centre.
Dig an uneven number of small holes (4-5 cm diameter, 15 cm deep, 20 cm spacing) along the circumference. Place 2-3 of the sticks (Ø = cm, length 1.8 m) vertical in the holes.

Compact the soil around the sticks and start "weaving" the thin horizontal sticks as in figure 5.4, C.

Add more vertical sticks until the circumference is filled. The horizontal sticks should be pressed tight together.

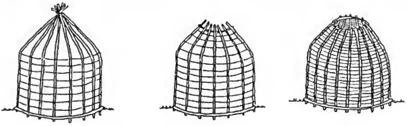
When the "weaving" has reached the height of shoulder, in this example 85 cm, one out of three vertical sticks can be cut to ease the "weaving" when the circumference is reduced.

The remaining vertical sticks are bent approximately 45^{o} towards the centre. Tie the sticks together right above the peg in the centre of the circle, see figure 5.5, A.

Continue the weaving until the inlet opening, a 50 cm wide hole in the centre.

Near the inlet opening more "vertical" sticks can be cut e.g. one out of two. The thinnest horizontal sticks are used near the inlet. When the size of the inlet opening has been reached, some fibres are tied round the upper 3-4 layers of horizontal sticks, figure 5.5, B.

Lift the bssket and tie the 3-4 bottom layers of horizontal sticks.
Cut the vertical stocks to a length of 2-3 cm beyong the weaving. Place the basket on top of the elevated platform or the stone base foundstion.



A B C

Figure 5.5: Building a basket type bin

A. Vertical sticks are bent and tied together over the centre peg

B. Preparing the lsst 3-4 layers of sticks around the inlet opening

C. Tying the last 3-4 layers in top and bottom together and cutting the vertical sticks in top and bottom.

a. Mud-clay lid, 50 cm diameter

b. Cement-sand lid, 50 cm diameter

Figure 5.6: Building the lid

Two thin sticks form the circumference of a circle, Ø = 70 cm. Cut 4 sticks and tie to the ring. Place and tie sticks close together and perpendicular to the 4 sticks until the whole ring is covered. Plaster the topside of the lid together at the same time as the basket.

Cut a hole close to the bottom for the outlet pipe. Tie some fibres around the hole and fix the outlet pipe.

The quality of the plastering will be improved if the shed structure is built before the plastering takes place.

Plaster the basket outside and inside, preferably at the same time. When the first layer of plaster is dry, smear with a thin mixture of cowdung-clay-water to make the walls smooth.

When cement: sand mortar is used for plastering, the following procedure should be used:

i) Cast a 3cm thick mortar layer on top of the foundation. Compact the mortar carefully with trowel and let it dry for an hour; then cover with grass, empty jute bags or leaves, to allow slow cursing.

ii) After 24 hours, remove the covering material and cast another 3cm layer on top of the first one. Level it and place the framework on top of the still wet mortar. Work the bottom of the framework into the mortar.

iii) Place the outlet carefully supported, and start plastering the outside of the framework. If the plastering is done in two layers, make sure that the first layer is left with a rough surface to ensure a strong bounding between the first and the second layer

iv) Use the trowel to make the surface smooth when the bin has cured for a few hours, and coat the bin with thick cement and water mortar.

v) Leave the bin to cure for two days before the plastering of the inside surface is done. After the first night, cover the bin with palm leave bags, etc. and add water 3 times per day to ensure damp conditions.

Leave the bin to cure for at least 45 days before loading with grain.

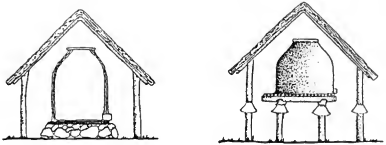


Figure 5.7: Two improved traditional bins.

When grain has been loaded into the bin the lid is sealed to the basket by a moist clay-soil-straw mixture.

6. DIMENSIONING THE BIN

The procedure for dimensioning a bin structure can be listed as below:

i) Calculate volume and weight of the product to be stored. See Table 4.5.

ii) Considering the identified constraint(s) on storage system, select bin component(s) for the construction from chapter 4.

iii) Calculate horizontal pressures on wall, see table 4.6.

iv) Check vertical load - footing area - safe bearing capacity of soil, see table 4.4.

v) Check strength of floor structure and vertical pressure

vi) Calculate and check tensile stress and strength in wall structures, see table 4.6 and equation 3.1 in chapter 4.2.2 or apply local experience.

vii) Produce a list of materials and quantities for the selected bin and alternatives, see tables 4.3 and 4.9.

Example: A farmer wants to store 30 bags (each 90 kg) of maize in a solid wall bin.

The procedure i to vii as shown above is as follows:

i) Weight: 30 bags x 90 kg/bag = 2700 kg total weight. The weight of $1m^3$ of maize is 719 kg (from table 4.5).
Volume: The total volume of maize will be $\frac{2700 \text{ kg}}{719 \text{ kg/m}^3}$ which approximates $4m^3$.

ii) The farmer chooses to build a 1.5 m diameter basket type bin on an elevated platform on a stone base (Chapter 5). The floor area of the bin will be: 3.14 x 0.75 x 0.75 = $1.8m^2$ (approximately). The height will be approximately: 2.2m.

iii) From table 4.1 the horizontal pressures can be obtained by extrapolation. This can also be obtained using equation 4.2,

$$P_h = \frac{719 \times 2.2}{102} \times \frac{(1-0.375)}{(1+0.375)} = 7.05 \text{ kN/m}^2$$

Thus the maximum horizontal pressure is approximately 7.05 kN/m^2.

iv) The vertical load from the bin structure can be estimated from list of materials, tables 4.3 and 4.9. It will be approximately 13 kN/m^2 including the foundation. The grain vertical load on the floor is 12 kN/m^2 (equation 4.3).

Thus the total vertical load will be approximately 25 kN/m^2 which is below the safe bearing capacity of even soft clay, table 4.4.

v) Since the floor structure is built directly on a stone base foundation there will be no strength problem for the floor.

vi) The farmer has chosen to build a basket type structure (maximum tensile strength = 8000 kN/m^2). From equation 4.7, the minimum wall thickness required for the wall is:

$$t = \frac{0.75 \times 7.05}{8000} = 6.6 \times 10^{-4} m \text{ or } 0.66 \text{ mm}$$

The thickness of the wall of basket type structure is generally about 8 cm. Therefore, there will be no strength problem for the wall, as long as the sticks stay free of rot and termites.

If only clay soil with 30 kN/m^2 of maximum tensile strength (table 4.7) was used for the construction of the wall, instead of basket type structure, the minimum thickness required for the wall should have been (from equation 4.7):

$$t = \frac{0.75m \times 7.05 \ kN/m^2}{30 \ kN/m^2} = 0.176m \text{ or } 17.6 \text{ cm}$$

Therefore, a 20 cm thick wall may be constructed using mud blocks without having strength problems.

vii) A fairly good estimate of the quantities necessary to build the bin can be obtained by calculating the area of all structural components and multiply by relevant figures from tables 4.3 and 4.9.

Foundation, stone base:	$0.5 \ m^3/m^2 \times 1.8 \ m^2 = 0.9 \ m^3$ stones
Floor, concrete slab (not reinforced):	$0.02 \ m^3/m^2 \times 1.8 \ m^2 = 0.04 \ m^3$ cement
	$0.05 \ m^3/m^2 \times 1.8 \ m^2 = 0.09 \ m^3$ sand
	$0.1 \ m^3/m^2 \times 1.8 \ m^2 = 0.18 \ m^3$ gravel
Walls, mud plastered basket:	$0.08 \ m^3/m^2 \times 12 \ m^2 = 1 \ m^3$ mud
	$10\text{–}40 \ m/m^2 \times 12 \ m^2 =$ 900 m sticks Ø 1-2 cm (approx.)
Additional materials:	$4 \ kg/m^2 \times 1.8 \ m^2 = 7.2$ kg bitumen
	or
	$0.5 \ kg/m^2 \times 1.8 \ m^2 = 0.9$ kg wax

To this should be added the quantity of material for construction of a shed for shading.

7. OPERATING THE BIN

Careful design and construction of a solid wall bin is just the first step towards safe storage of grains.

The second step is proper management of the bin. This includes the following measures:

7.1 DRYING THE RECENTLY BUILT BIN BEFORE LOADING GRAIN INTO IT

This point is important for all mud-soil-cement built bins since it is common practice to operate with cement:sand(soil): water mixtures having a water:cement ratio 0.5-0.7 by weight. However, to complete the chemical reactions in the cement:sand:water mixture, a water: cement ratio of only 0.15 is needed. The excess water is bound in minor pores and some 6 weeks are necessary to dry the structure to an acceptable moisture content. Such long drying period will also allow for repair of cracks that might appear because of the drying.

7.2 CLEANING THE BIN BEFORE LOADING AND WHEN EMPTY

Even if the bin is new, the inside walls and the floor should be carefully swept and all dust removed before loading grain into the bin.

At the same time the wall should be inspected for minor cracks being visible looking from the dark interior of the bin towards the bright sunshine outside the bin.

The cleaning should also be performed after the bin is emptied. Some insecticide powder may be sprinkled over the floor and the bin should be carefully sealed until it will be loaded with grain again.

Fumigation might be an alternative, but usually some expert assistance is required to handle the extremely poisoneous chemicals.

7.3 USE OF FUMIGATION OR INSECTICIDE POWDER WHEN LOADING THE BIN

It has been stated in the previous sections that only the steel containers can be expected to provide sufficient airtightness and thereby kill all insects in the stored product by natural reduction of the oxygen content.

All other bin structures will show some leakiness. The magnitude of such leak cannot be determined by any practical means at the present time. Therefore, it is strongly recommended to treat the grain using the proper pesticide (according to the recommendations of the Plant Protection Service) when the bin is loaded or just before.

7.4 LOADING - UNLOADING THE BIN

Most of the bin structures have a very brittle surface, in particular those plastered with mud, but also the soil:sand(cement) structures are vulnerable to physical pointloads. Most bins holding more than 10 bags of grain are loaded by a person standing on a ladder resting on the upper end of the bin. Such practice can easily damage the bin surface, and wherever possible the ladder should rest on a horizontal beam connected to the shed structure in some way.

If unloaded grain from the bin shows any sign of mouldy odour, high frequency of insects etc., the bin should be emptied immediately and the grain redryed and replaced mixed with the recommended dose of insecticide.

7.5 MAINTAINING THE BIN

All bin atructures require some maintenance. The bin structures mentioned in the previous sections may be listed according to their need for maintenance.

i) Metal bin structures need no maintenance if made of galvanized iron sheets. If made of plain iron sheets they might require anticorrosive painting every 2-3 years in coastal regions and every 5-7 years in upland humid climate.

ii) Cement:sand plastered structures need careful inspection and repair once a year. Such work should be carried out at least 2 months before the bin is supposed to be loaded with grain.

The maintenance comprises the repair of cracks with either cement: waterslurry, paint or lime.

iii) Mud plastered structures should be inspected from the outside every two weeks when grain is stored in the bin and every month when empty. This is to avoid severe losses due to insects penetrating the wall through cracks and to reduce disintegration of the structure due to a leaking roof structure, attack by rodents, birds or termites.

Usually the maintenance will be reatricted to additional plastering and coating with cowdung: water mixture.

iv) Foundations: The foundation should be kept firm to avoid leaning of the floor and wall structure, which will cause considerable cracking. Thus the foundation should be inspected once a year; the stone and brick foundations for loose stones and the pole foundation for loose ratguards and attack from termites. Wood preservation may be added to the poles every year.

8. COST-BENEFIT ANALYSIS

The cost and benefit of constructing and using a solid wall bin for storage of farm produce cannot be calculated to any relevant degree of accuracy unless the local conditions are taken into consideration.

In table 8.1, a scheme is introduced for analysing the costs of constructing the bin as well as the costs of storing grain and pulses.

To fill in lines C,D and F in the scheme, it is necessary to estimate the lifetime of the structure as well as the costs of maintenance per annum.

The lifetime of the improved bin structure described in previous chapters is supposed to be 5-20 years and the maintenance limited to be labour costs for one or two days per annum. If a thatched roof and mats are used to cover the walls in the storage period, it might be necessary to renew the roof once every 3-5 years.

Obviously some of the specifications in the scheme can be neglected because of local conditions. It is, however, recommended to consider all specifications when alternative structures for storage are compared.

Interest for capital bound in the produce during the storage period (item G) will sometimes be balanced by the increased price for the product in the same period.

Estimating the magnitude and value of dry matter and qualitative losses (item K) is probably the most controversial and inaccurate task in the cost-benefit analysis. Loss estimates based on experience from tropical regions indicate that proper handling of grain stored in well built and maintained bins will reduce losses to 2-3% or less when stored less than one year. It is, however, strongly recommended to get hold of experimental results from the local area to complete the cost-benefit analysis.

Because of prevailing climatic conditions in some areas, it may be necessary to include the costs of drying by artificial means in the cost-benefit analysis (item J).

Comments on table 8.1:

A. Cost of building materials includes both the bin, additional shelter, padlocks etc.

B. Cost of labour. Wherever there is a possibility of alternative earning, this should be considered as cost of labour.

C. Depreciation per annum. The different structures and different climatic conditions will allow for different life span of the bin. A rough estimate is given below:

Bin structure	Expected lifetime
Mud plastered basket	5-90 years depending on maintenance
Solar dried mud blocks	5-20 years " " "
Ferro cement bin	5-30 years " " "
Burnt brick bin	5-30 years " " "
Metal container	more than 30 years

The farmer has to estimate the life span according to local conditions and ability to maintain the bin structure. Often the shed structure may be rebuilt several times before the bin is worn out. Depreciation per annum can then be calculated as

$$\frac{A + B}{\text{life span}}$$

D. Interest per annum can be estimated as

$$\frac{(A + B) \times \% \text{ interest}}{2 \times 100}$$

E. Sum capital costs per annum are C + D. These costs are usually paid when the bin has been built or within some 5-10 years if the farmer has got a loan.

F. The costs of maintenance per annum vary considerably according to bin structure, climatic conditions, and the farmer's intentions to prolong the life span of the structure.

G. Interest for capital bound in the produce is based on the assumption that if the farmer sells the produce immediately after harvest, he might place the money in a bank and be payed some interest. G can be calculated as:

$$\frac{\text{Value of produce at harvest} \times \text{Bank interest } \% \times \text{Storage period}}{12 \text{ months} \times 100\%}$$

H. The costs of chemicals and fumigation are straightforward to fill in the scheme.

I. This includes costs of labour for operating the bin. For further comments, see B.

J. Drying costs: if the grain has to be artificially dried before storage.

K. Estimated value of losses. The farmer may also estimate the percentage according to his own or local experience.

L. This is just the sum of all variable costs per annum. They usually have to be paid throughout the storage period.

M. Total costs per annum. This figure can be compared to the costs of alternatives structures if they all have the same storage capacity. Otherwise it is necessary to proceed through item N to R to obtain figures that can be utilized to compare costs of storing in different solid wall bins.

N. Also the figures in N might be used to estimate the sales prices necessary to balance the costs of storing one kilogram of produce.

Table 8.1: Scheme for analysing the costs of storage in different solid wall bins.

	Specifications	Traditional structure	Alternative 1	Alternative 2
A	Cost of building materisls			
B	Cost of labour			
C	Depreciation per annum			
D	Interest per annum			
E	**Sum capital costs per annum**			
F	Maintenance per annum			
G	Interest for capital bound in produce			
H	Chemicals			
I	Labour (loading, spraying etc.)			
J	Drying costs			
K	Estimated value of losses			
L	**Sum variable costs per annum**			
M	**Total costs per annum, E + L**			
N	Amount of produce stored per annum — Product 1			
O	Produce 2			
P	Produce 3			
Q	Total amount of produce stored per annum			
R	**Total costs per kg of produce stored per annum**			

9. CONCLUSIONS AND RECOMMENDATIONS

A properly built, well maintained and well managed solid wall bin can without any doubt contribute to considerable reduction of post-harvest losses in terms of both quantity and quality.

To be successful in that respect it is, however, important to emphasize the recommendations listed below:

i) The moisture content of the grain or pulse must be below the recommended maximum values before being loaded into the sealed bin. Measures must be taken to make the bin as insect proof as possible.

ii) Grain loaded into the bin must be clean, free of soil, parts of husk and straw etc.

iii) Insecticidal treatment is always recommended in the sealed solid wall bin.

iv) Opening of the bin during storage should be restricted to what is absolutely necessary and it is recommended to combine the long term storage in the bin with a short term storage in a clay pot etc. from where the daily need for grain can be met.

v) Proper maintenance of the outer wall surface is important to avoid cracking which will allow insects to penetrate the wall.

vi) Wherever possible and appropriate the farmer should select bin structures with a minimum of wooden material present in the clay or concrete walls.

vii) It is necessary to provide all bin structures with an additional climatic shelter.

ANNEX 1: CONSTRUCTION DETAILS OF SOME SMALL STORAGE BINS

A-1 : Ferrocement bin ("Ferrumbu")

A-2 : Dome shaped roof bin ("Gourmabin")

A-3 : Mud brick silo

A-4 : Double walls rectangular bin (Pusa bin)

A-5 : Metal bins

A-1 : Ferrocement bin ("Ferrumbu")

List of materials:

24 straight sticks, Ø = 2-3 cm, length = 10-15 cm longer than the height of the bin.
16 straight sticks, Ø = 2 cm, length 50-60 cm.
Thin sticks, less than 1 cm Ø, made of fresh-cut split bamboo, lantana, mulberry, etc. The length according to the bin height and diameter. The spacing between the circumferential sticks is assumed to be 15 cm.
A few 3-4 cm nails.
Cement, sand and chicken wire according to table A.1.

Table A.1: The amount of cement, sand and chicken wire, 12 mm, for different ferro cement bins

Inside diameter	Height to the shoulder, H	Approx. capacity	Thickness of wall	Layers of wire	Cement	Chicken wire
100 cm	100 cm	0.9 m^3	3.5 cm	2	3 bags	17 m^2
110 cm	110 cm	1.2 m^3	-	-	4 bags	20 m^2
120 cm	120 cm	1.6 m^3	-	-	4 bags	23 m^2
130 cm	130 cm	2.0 m^3	-	-	5 bags	25 m^2
140 cm	140 cm	2.5 m^3	-	-	6 bags	28 m^2
150 cm	150 cm	3.1 m^3	-	-	6 bags	32 m^2
160 cm	160 cm	3.8 m^3	-	-	7 bags	36 m^2
170 cm x)	170 cm	4.5 m^3	5 cm	-	9 bags	45 m^2
180 cm x)	180 cm	5.3 m^3	-	-	10 bags	50 m^2
190 cm x)	190 cm	6.3 m^3	-	-	12 bags	55 m^2
200 cm x)	200 cm	7.3 m^3	-	-	13 bags	60 m^2
210 cm x)	210 cm	8.5 m^3	-	-	14 bags	65 m^2
220 cm x)	220 cm	9.7 m^3	-	-	15 bags	70 m^2
230 cm	230 cm	11.1 m^3	6 cm	3	17 bags	90 m^2
240 cm	240 cm	12.7 m^3	-	-	19 bags	98 m^2
250 cm	250 cm	14.4 m^3	-	-	21 bags	106 m^2

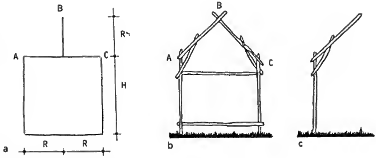
x) Up to one metre from the bottom of these structures there should be 3 layers of chicken wire.
The necessary amount of sand is 4 times the amount of cement (measured in volume units).
The shed, which is required for proper temperature and moisture control, has to be built before plastering the bin.

Foundations:

The foundation is built according to figure 5.1 or 5.3.

Building the framework:

A "drawing" of the main framework of the Ferrumbu can be traced by stick or nail on a levelled ground according to figure A.1.



H = Height to shoulder
R = Radius of the bin

Figure A.1: Making the frames for a ferrocement bin

a = "Drawing" made according to figures from table A.1 and the selected size of the bin
b = Complete frame. Only one is made.
c = Half frame. There should be made 6 of them.

Place the aticka on top of the "drawing" on the ground and fix them together by nail, wire, fibre etc. Trace a circle on the ground according to figure A.2 a. Place the complete-frame over one of the diameter lines in figure A.2 a. Place a half-frame perpendicular to that one and join them by two crossed poles at the bottom and close to the bending, figure A.2 b. Continue the process with the remaining 5 half-frames.

Tie the thin (1 cm) sticks horizontal on the outside of the frames. Wire is to prefer for this operation. The space between the "rings" ahould be approximately 15 cm. The upper ring is placed where the diameter is approximately 50-55 cm. This will be the inlet opening.

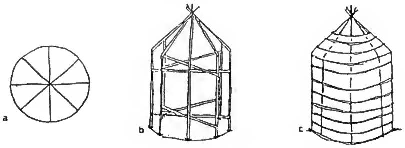


Figure A.2: Making the framework for a ferrocement bin.

Fixing the chicken wire:

Two layers of crossed chicken wire are used for the bottom. The width is 20 cm more than the diameter and the length 100 cm more than the diameter. Tie them together with wire and place the wooden framework on top of it, see figure A.3.

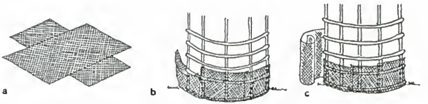


Figure A.3: Fixing the chicken wire

a. Two layers of chicken wire
b. Chicken wire bent up around the framework and tied to the horizontal sticks (laths)
c. Chicken wire wrapped around the framework.

One piece of chicken wire is wrapped around the frame and tied to the laths. Wrap a new layer above this and continue until the bin is covered with a double layer of chicken wire a bit higher than the cylindric part of it.
Allow 10 cm overlap of the mesh in all joints. Fold and bend the top of the mesh inwards into the cone shape (45° inwards).
Use additional pieces of chicken wire to form the cone part, leaving an inlet opening, a few cm wider than the final hole, 50 cm. Tie the mesh properly together and to the laths , thus creating a firm framework for plastering.
Cut a 20 x 20 cm hole for the outlet, figure 4.9, and bend the flaps out and up. For construction of outlet, see section 4.3.

Plastering:

The shed required to protect the bin against climatic influence should be built before plastering takes place.

Mix cement and sand 1:4 by volume. Cast a 3 cm thick mortar layer on top of the foundation. Compact the mortar carefully with a trowel. Let it dry for an hour, then cover with grass, empty bags, leaves etc.

After 24 hours, remove the cover and cast another 3 cm layer on top of the first one. Level it and place the framework on top of the still wet mortar. Work the bottom of the framework into the mortar.

Place the outlet carefully supported, and start plastering the outside of the framework to cover the chicken wire.

If the plastering is done in two layers, make sure that the first layer is left with a rough surface to ensure a strong connection between first and second layer.

Use the trowel to make the surface smooth when the bin has cured for a few hours, and coat the bin immediately with a thick cement and water paste.

Leave the bin to cure two days before the inside plastering is done. After the first night, cover the bin with palm leaves, bags etc. and add water 3 times a day to ensure damp conditions.

Plaster the bin inside and finally make a 2-3 cm thick floor layer with a concave moulding along the wall. Plaster carefully around the outlet pipe. Leave the bin to cure 6 weeks before loading with grain.

Making the lid:

The same size lid is used for all sizes of "Ferrumbus". The diameter is 70 cm and the pitch 45°, see figure A.4.
Form a "hat" of thin poles (1-2 cm). Hold them firm by laths on the outside. Cover it with chicken wire.
Plaster it thinly outside and let it cure for 2-3 days. Turn it upside down and place it in a small hole to keep it in the right position.
Take away the wooden frame leaving the laths. Plaster the inside. Keep it well damp during curing.
Arrange for a lock device or a wooden plug for sealing the outlet and a worn out bicyle tyre for sealing of the inlet opening, see figures A.4.

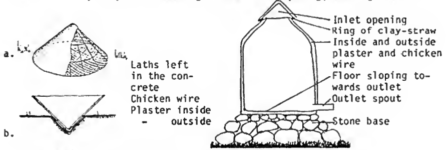


Figure A.4: The lid (a and b) and the completed "ferrumbu".

A-2 : Dome shaped roof bin ("Gourma Bin")

This type of bin has been designed and introduced by the FAO Prevention of Food Losses project in Fada NGourma (Burkina Faso). It consists basically in a mud block bin built on an elevated stone basis, with the upper part of the bin (or roof) having the shape of a dome (figure A.5).

List of materials:

(For 1000-1200 kg capacity)

- 150 to 200 mud blocks (20 x 15 x 10 cm);
- 120 mud (or cement-mud, with 4% of cement) briquettes, 20x10x6 cm or similar size;
- cement, sand, gravel, mud;
- metal sheet, 0.5 mm thick for outlet;
- bitumen;
- thatched roof.

Foundation:

At first, the geometric center of the bin needs to be determined and materialized by an iron rod driven into the soil (figure A.6). This iron rod will later be used to support an instrument intended to build the dome roof. Then the foundation is built according to figure 4.4 or 5.3.

Construction of the wall:

The wall is built using mud blocks as in figure 4.5 c. A soil with adequate clay content - 25 to 40% of clay - should be used for the mud blocks. For more stability and strength, chopped grass should be added and thoroughly mixed to the mud soil. Curing of the freshly made blocks should be carried out under the shade or with the blocks covered with straw, leaves or used jute bags and sprinkled with some water 3-4 times per day. During the construction of the wall, the same mixture of mud and chopped grass should be used for the joints between the blocks and for plastering.

Construction of the dome:

The iron rod indicating the geometric center of the bin supports a vertical piece of wood on which a revolving radius or "arm", also in wood, is fixed (figure A.7). For a spheric dome, the vertical connection of the "arm" and the wooden support should be at the same height as the top of the vertical wall. The extremity of the arm is fitted with another piece of wood called "pistol" because of its shape (figure A.8). In order to have the proper inclination of the successive layers of briquettes, the "pistol" has a downward slope ($10-15^{o}$) from the center line of the arm as in figure A.8. Therefore during the construction, each briquette is laid and adjusted to the proper sloping using the "pistol".
The successive layers are built up to the point where just an opening with 60 to 50 cm in diameter is left as the inlet of the bin.

Construction of the inlet and outlet:

The inlet and the outlet are constructed according to systems described in chapter 4.3. The bin should always be provided with a shelter or fitted with an overhanging thatched roof for protection against rain and solar radiation.

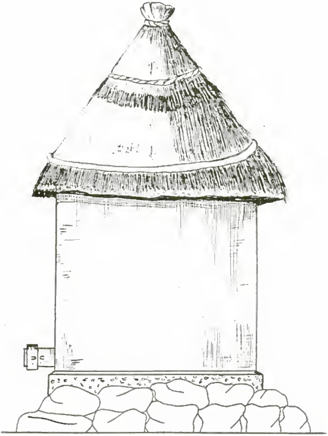


Figure A.5: The "Gourma bin"

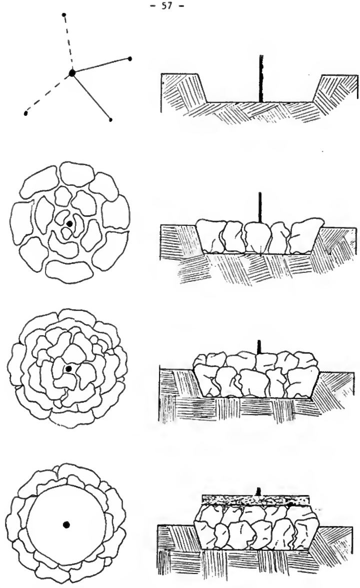
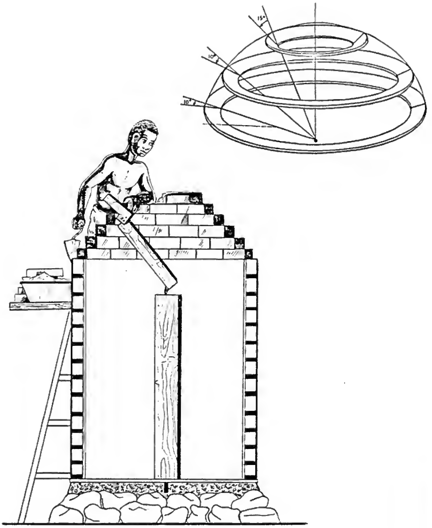
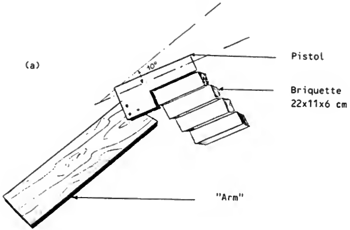


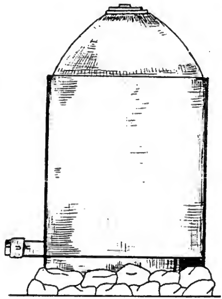
Figure A.6: The different steps followed for the construction of the foundation and floor, and the materialization on the geometric centre of the bin.



<u>Figure A.7</u>: Construction of dome shaped roof in successive layers of briquettes, using the "pistol".

(a)





(b)

Figures A.8: a) The mobile radius (or the "arm") and the pistol.
b) Completed bin (without roof).

A-3: Mud brick silo

List of materials:

325 mud-bricks 10 x 10 x 15 cm	2-3 bags of cement
18 m iron bars, Ø 6 mm	Sand, lime and gravel
(the iron bars may be replaced by chicken wire)	Straw and sticks
2 litres of coal tar or bitumen	

The silo can be built either directly on the ground or on a concrete slab resting on 4 concrete or burnt bricks pillars (see figure A.9). The walls consist of mud bricks plastered inside and outside with cement: sand mortar, 1:4, and made "waterproof" by painting with coaltar. It is necessary to balance the tensile stress in the wall with 3 or 4 wires or chicken wire as shown in figure A.9. The silo is topped by a concrete slab with an inlet opening and a cover made of straw. A shed structure might be used as well. If possible the bin walls should be white painted.

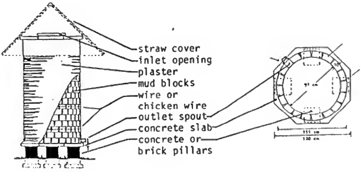


Figure A.9 a. Mud brick silo, front b. Mud brick silo, cross section

A-4: Double wall rectangular bin (improved Pusa bin)

List of materials: (inside dimensions 160 x 100 x 140 cm)

3 bags of cement for mortar	130 mud bricks (10x10x15 cm)
1.1 m^3 of sand for mortar	12 m^2 Polythene sheet
16 m of poles, Ø > 6 cm	(0.25 mm/700 Ga)

The bin has a double wall all the way round, including the floor and roof, see figure A.10.

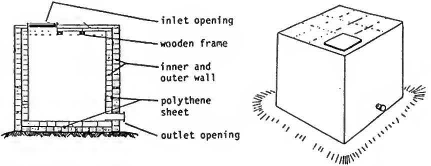


Figure A.10: A double wall Pusa bin with plastic sheet lining.

a. Perspective view
b. Cross section

It is necessary to place the bin under a shelter or in the dwelling house where it could be built in s corner as part of the house. Between the walls there is a separating layer of plastic sheet. The roof is supported by a wooden frame structure resting on the inside wall.

Where rats cause great problems, the bottom layer of the floor slab and some 50 cm of the outside wall should be made of burnt bricks or protected by sheet metal.

A.5: Metal Bins

The most widespread metal container is the 200 litre oil barrel that can hold approximately 150 kg of maize. Thus a farmer and his family will need approximately 6 barrels to store the harvest meant for consumption. This will probably be too expensive. A more appropriate metal container may be produced out of 4.5 plain iron sheets 2 x 1 m and thickness of approximately 0.5 mm.

A 2 metre high cylinder is made of 3 iron sheets joined at the longitudinal edges, see figure A.11.

Bottom and top are cut from another sheet and joined to the cylinder, figures A.12 and A.13.

Inlet and outlet openings are made according to figure A.14.

The strength of the container wall is improved by 2 metal wires as shown in figure A.15.

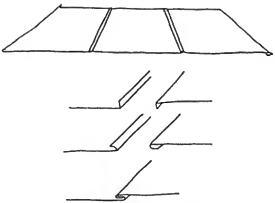


Figure A.11 a. Joining 3 metal sheets at the longitudinal edges.
b. Detail of the joint. The joint has to be supported by a wooden board when hammered.

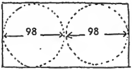


Figure A.12: Cutting bottom and top from one metal sheet.

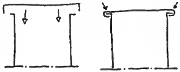
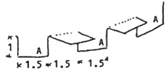
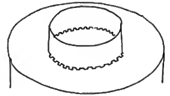


Figure A.13: Connecting top and bottom to the cylindric wall. The joint should be made moisture and insect proof by smearing wax, glue, bitumen etc. into the joint from inside of the cylinder.





a. Detail of inlet and outlet opening

b. Inlet opening

Figure A.14: Design of inlet and outlet openings. When mounted at the top and in the wall all "A" taps are bent against the top or wall to fix the opening. The connection is sealed with a layer of bitumen.

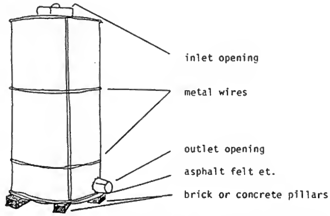


Figure A.15: Complete metal container with wires to strengthen the wall. The metal bin should be placed under a shelter giving full shade to all wall area.

ANNEX 2

SIMPLE SOIL TEST FOR CLAY CONTENT DETERMINATION

In order to decide whether soils are suitable or not for mud blocks or soil-cement blocks the following test should be carried out:

i) Remove the top-soil (any dark soil with roots and plants in it). Dig a hole, 1.5 m deep.

ii) Take half a bucket of soil, from just below the top-soil, and from the bottom of the hole. Both samples should be sun dried, then mixed together.

iii) Take a clear glass bottle and fill it 1/3 full with soil from the mixed sample. Particles which are larger than 10 mm should be removed.

iv) Take a 1/4 to 1/2 tea-spoon of salt and mix it with water. When the salt has dissolved, the mixture is transferred into the bottle containing the soil sample.

v) Add water until the bottle is 2/3 full (figure A.16). Shake thoroughly and let settle for one hour. Then shake once more and let settle for 8 hours.

vi) After this settling time, the larger particles will be seen at the bottom of the bottle, while the smaller ones rest on top. There will be a fairly distinct line. Below the line the individual particles can be seen with naked eye, but above they cannot be separated. The lower layer consists of sand and gravel while the top layer consists of silt and clay (figure A.17).

vii) The percentage of clay and silt is calculated from the following equation:

$$\% \text{ clay \& silt} = \frac{a}{h} \times 100$$

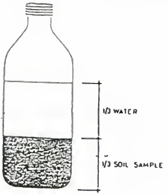


Figure A.16

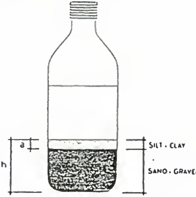


Figure A.17

viii) If the silt and clay content is larger than 40%, the soil is not suitable for cement stabilization. It should not be used for mud blocks either. If the clay and silt content is between 10 and 40%, the soil may be suitable for making blocks.

A soil may have the right silt and clay content, but still be laborious to work with. If it is very lumpy and difficult to prepare and mix, then it is not suitable.

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